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S.N. Ogbuehi

James R. Brandle

University of Nebraska - Lincoln, jbrandle1@unl.edu

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Influence of Windbreak-Shelter on Soybean Growth, Canopy Structure, and Light Relations[1]

S. N. Ogbuehi and J. R. Brandle[2]

ABSTRACT

Although changes in canopy morphology of soybeans [*Glycine max* (L.) Merr.] grown in windbreak-sheltered plots have been reported, how these changes affect the canopy light climate has not been evaluated. This information is needed for a better understanding of the mechanisms of shelter influence on soybean production, and for satisfactory models of soybean growth and yield under these conditions. The objectives of the field study reported here were to determine the influence of windbreak-shelter on soybean canopy morphology, canopy light climate, growth, and bean yield. 'Wayne' soybeans were grown during the 1978 and 1979 growing seasons under windbreak-sheltered and exposed conditions at the University of Nebraska Field Laboratory, Mead, Nebraska. The soil was a *Typic Arguidoll* (Sharpsburg silty clay loam).

The sheltered soybeans were characterized by a significantly lower leaf area density and leaf density, and smaller leaf size in the uppermost portions of the canopy in comparison with those grown in exposed plots. Consequently, there was a greater penetration of the incident photosynthetically active radiation to lower canopy strata in sheltered soybeans.

Even though available soil water was similar for the treatments, sheltered soybeans had a more favorable plant water status. This was probably a consequence of lower atmospheric evaporative demand in shelter due to reduced wind-speed. Crop growth and bean yield were significantly increased in shelter obviously because of the better plant water status and canopy light climate. The number of pods per plant, seeds per pod and harvest index were increased in shelter.

Since soybean yield is limited by restriction of light penetration to lower canopy strata, cultivar selection on the basis of this morphological response to shelter should lead to increased soybean production. Models for predicting soybean performance need to accommodate any changes in canopy morphology.

Additional index words: *Glycine max* (L.) Merr., Climate, Models of growth.

THE efficient use of solar radiation by a plant community depends on the amount of light intercepted, the distribution of this light within the canopy, and on the photosynthetic rate of individual leaves. Light interception and distribution in the canopy are a function of canopy structure (12). Therefore, through its influence on canopy light climate, canopy structure can be an important determinant of crop productivity (13, 16). A soybean [*Glycine max* (L.) Merr.] canopy is characterized by a very dense leaf layer in the uppermost portion (2). As a consequence, most light interception occurs in this upper layer, while light penetration to lower canopy strata is severely restricted (20, 21). Experiments involving the addition of supplemental light to middle and lower soybean canopy strata have demonstrated significant increases in bean yield (8).

Some morphological changes in soybeans grown in windbreak-sheltered plots have been reported (6, 14). How these affect the canopy light climate has not been evaluated. This information is needed for a better understanding of the mechanisms of shelter influence on soybean production, and for satisfactory models of soybean growth and bean yield under these conditions. The study reported here was designed to study the influence of windbreak-shelter on soybean canopy morphology, canopy light climate, growth, and bean yield.

MATERIALS AND METHODS

'Wayne' soybeans were planted on 19 May during 1978 and 1979 growing seasons under windbreak-sheltered and exposed conditions. Plant rows, 92 cm apart were oriented in a north-south direction. The study was carried out at the University of Nebraska-Lincoln Field Laboratory, Mead, Nebraska (41° 29' N; 96° 30' W; 354 m above mean sea level) under dryland field conditions. The soil was a *Typic Argiudoll* (Sharpsburg silty clay loam). Soil water at 1/3 and 15 bars was 35 and 16%, respectively. A system of east-west oriented shelterbelts (6 m high, and about 60% dense) established in 1964 for windbreak research, provided shelter from wind. The prevailing winds in Nebraska during the summer months come mainly from the south. Each windbreak consisted of two rows of trees, made up of green ash (*Fraxinus pennsylvanica* L.), Austrian pine (*Pinus nigra* Arnold), and eastern redcedar (*Juniperus virginiana* L.). Experimental plots (9 × 10 m) were randomly located within a bean field of approximately 1.6 ha. The sheltered plots were located north of the windbreaks at distances of 1H, 2.5H, 4H and 6.5H (H = windbreak height). The exposed plots were located 1 km east of the windbreaks, and therefore outside their area of influence. Soil chemical analyses for N, P, K and pH were similar for all plots. The layout was a completely randomized block design with four replications.

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[2]Research associate, UMUAHI, Imo State, Nigeria WA and associate professor, Dep. of Forestry, Fisheries and Wildlife, Univ. of Nebraska-Lincoln, Lincoln, Nebraska 68583.

Precipitation and wind-speed (at 2 m above the canopy) were monitored daily with standard meteorological instruments installed at each plot site. Available soil water determinations based on gravimetric soil samples taken to a depth of 30 cm were made once a week starting at Growth Stage V1 (4). During sampling, two soil samples were taken from the center of each plot. The soil water content at 15 bars, determined for the 0 to 30 cm soil depth was used to calculate the available soil water. Available water was taken as the water in excess of the wilting coefficient. Starting at Growth Stage V2, estimates of dry matter production and leaf area index (LAI) were made once a week by cutting plants at ground level from four randomly selected meter-length row segments within each plot. The samples were taken to the laboratory where the leaves were separated from the stems. Height and leaf area of the cut plants were determined. Leaf area was measured with Model LI-3000 area meter, and an accessory transparent belt conveyor, Model LI-3050 (Lambda Instr. Corp.). Plant parts were oven dried to constant weight at 70 C. With the data on leaf area, LAI was calculated.

On 2 days in 1978, and 4 days in 1979, the distribution of leaf area density (LAD), leaf density and leaf size with canopy height was studied by the stratified clip method of Monsi and Saeki (12). Gradients of photosynthetically active radiation (PAR) in the canopy were determined twice after canopy closure during each growing season. The stages of plant development were R5 and R6. PAR was measured one meter above the crop and at heights in the canopy corresponding to 85, 70, 50, 40, 10, and 0% of canopy height. Because there were treatment differences in plant height, relative height in the canopy had to be used for comparative purposes. Measurements of PAR were made using the Quantum Sensor, Model LI-191S (Lambda Instr. Corp.). This sensor averages PAR over a one-meter length. An aluminum stand with adjustable height facilitated measurements of PAR at desired heights within the canopy. At each canopy height, the sensor was held parallel to the row, and as close as possible to the center of the row. One PAR reading was taken on the east side of the row, and another, on the west side. PAR measurements were made four times daily at 1000, 1300, 1500, and 1800 hours (solar time) to average out sun angle effects. Following these measurements, the distribution of LAI with canopy height was obtained using the stratified clip method, in order to establish the relationship between these. With the data on LAI and PAR above and within the canopy, PAR extinction coefficients (K) were calculated.

Leaf water potential was evaluated 1 day a week (1200 to 1400 hours) using the pressure chamber (19). The center leaflet of the uppermost fully-expanded leaves was used for measurements. At each sampling period, measurements were made on four randomly selected leaves in each plot. Bean yield estimations were made at maturity on plants clipped from four meter-length row segments randomly selected within each plot.

Because shelter effect varies with distance from windbreak (23), data from the sheltered plots were pooled to average out the effect of location. The pooled data provides a better estimate of the overall shelter influence than data obtained from only one location in shelter.

RESULTS AND DISCUSSION

Plant height, LAI, dry matter production and bean yield were significantly increased in shelter during both years (Tables 1 and 2, and Fig. 1), obviously because of a better plant water status (Fig. 2). Plant water status is a function of available soil water and atmospheric evaporative demand, and influences crop growth, development and yield (15, 22). Since available soil water was similar for both treatments (Table 3), the improved plant water status in shelter must have resulted from reduced atmospheric evaporative demand due to reduced windspeed 23). The average wind-speed in shelter for June throu August was 51 and 57% of that in exposed plots duri 1978 and 1979, respectively (Table 3). Increased pla growth and yield in shelter have been reported for vario

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Year	Month	Plant height†		Leaf area index‡	
		Exposed	Sheltered	Exposed	Sheltered
		cm			
1978	June	14.1 a*	16.5 a	0.4 a	0.5 a
	July	51.2 a	60.4 b	2.7 a	3.3 b
	Aug.	101.3 a	114.7 b	4.1 a	5.8 b
	Avg.	55.5 a	62.5 b	2.4 a	3.2 b
1979	June	10.9 a	11.7 a	0.2 a	0.2 a
	July	31.9 a	38.6 b	1.7 a	2.0 b
	Aug.	73.0 a	90.3 b	3.7 a	4.5 b
	Avg.	38.6 a	46.9 b	1.8 a	2.2 b

* Means in rows under the same variable followed by different letters are significantly different at the 5% level using L.S.D.
† Average of 64 measurements.
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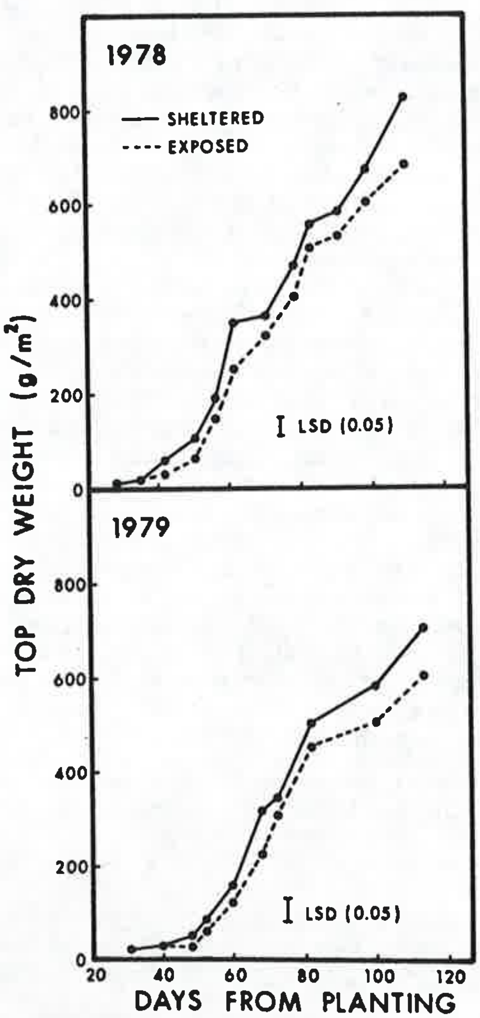

Fig. 1. Seasonal trends of top dry weight of sheltered and exposed soybeans during 1978 and 1979 growing seasons.

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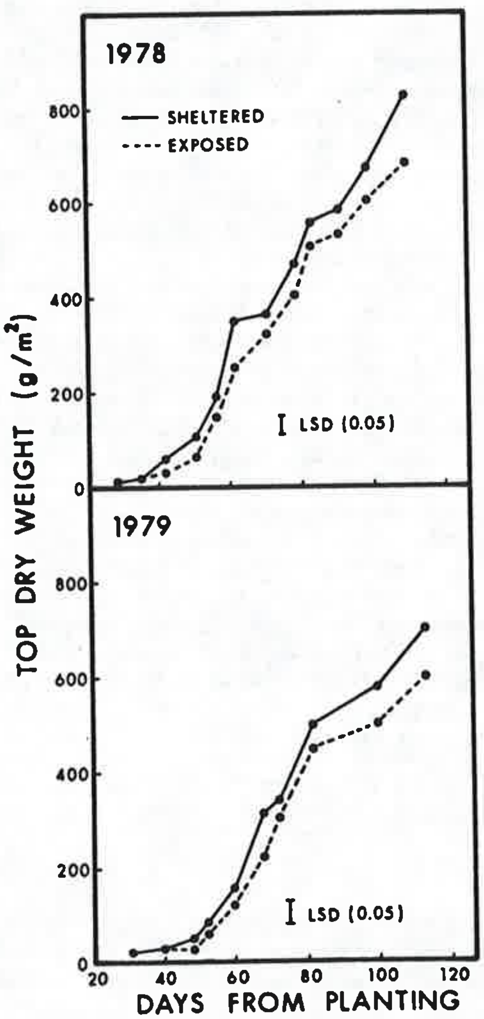

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Sheltered soybeans flowered 4 and 10 days earlier than those in exposed plots in 1978 and 1979, respectively. Even though pod filling started earlier in shelter, physiological maturity was attained about the same time in both treatments. This meant a longer pod filling period for sheltered soybeans. Earlier flowering in shelter has been reported for various crops including corn (24) and tomatoes (1). Data on yield components (Table 2) indicated that the number of pods per plant and seed per pod were significantly greater in shelter. In an experiment involving the addition of supplemental light to middle and lower soybean canopy strata, Johnson et al. (8) noted that the number of pods per plant and seeds per pod were increased. In our study, harvest index (ratio of reproductive to vegetative growth) was also significantly greater in shelter; and together with number of pods per plant, seeds per pod, and pod filling period accounted for the greater bean yield in shelter.

Sheltered soybeans were characterized by a significantly lower LAD in the uppermost portions of the canopy in comparison with those in exposed plots (Fig. 3). Lower LAD implies greater spatial separation of leaves

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		cm	cm		
1978	June	14.1 a*	16.5 a	0.4 a	0.5 a
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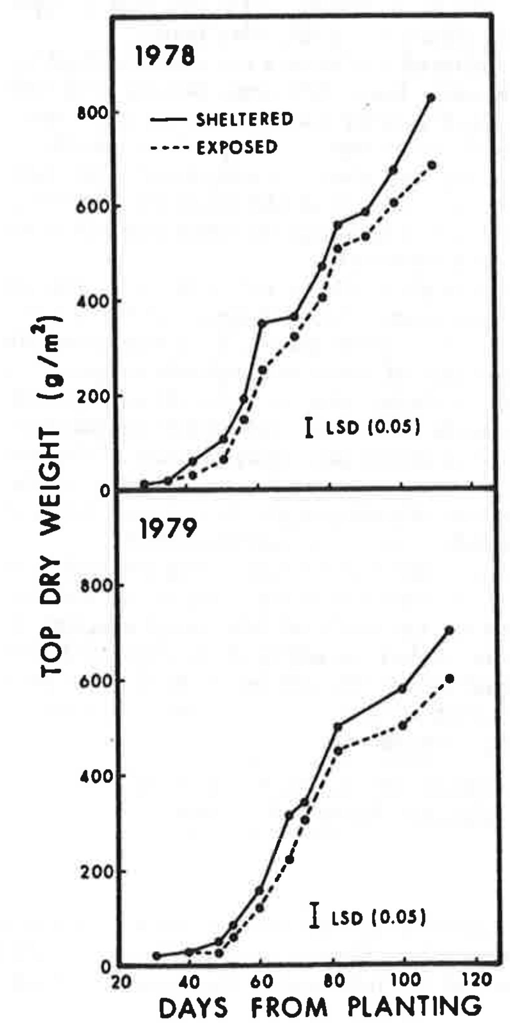

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Table 2. Yield and yield components of sheltered and exposed soybeans in 1978 and 1979.

	Year	Exposed	Sheltered
Pods/plant	1978	40.0 a*	44.4 b
	1979	30.1 a	36.5 b
	Avg	35.1 a	40.5 b
Seeds/pod	1978	2.3 a	2.4 b
	1979	2.2 a	2.4 b
	Avg	2.3 a	2.4 b
Harvest index	1978	0.48 a	0.52 b
	1979	0.46 a	0.48 b
	Avg	0.47 a	0.50 b
Yield (kg/ha)	1978	1,647 a	1,980 b
	1979	1,436 a	1,815 b
	Avg	1,541 a	1,898 b

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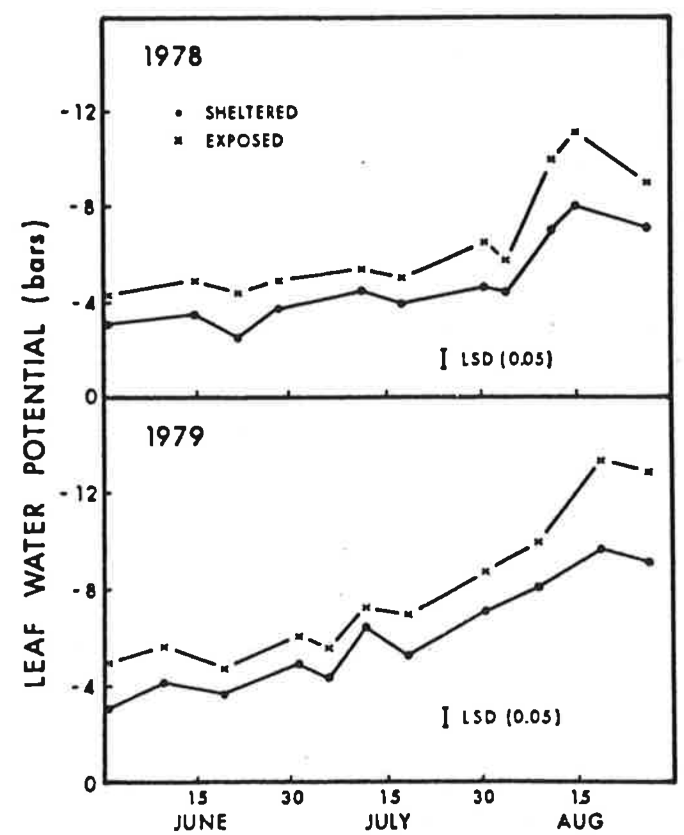

Fig. 2. Seasonal trends of leaf water potential of sheltered and exposed soybeans during 1978 and 1979 growing seasons.

Table 3. Mean monthly available soil water and wind-speed in sheltered and exposed soybean plots during 1978 and 1979 growing seasons.

Year	Month	Available water† Exposed	Available water† Sheltered	Avg 24-hour wind Exposed	Avg 24-hour wind Sheltered
		mm	mm	km	km
1978	June	10.3 a*	11.5 a	-	-
	July	8.1 a	8.4 a	7.5 a	3.9 b
	Aug.	5.2 a	6.1 a	7.7 a	3.9 b
	Avg	7.8 a	8.6 a	7.6 a	3.9 b
1979	June	8.9 a	10.4 a	13.5 a	8.1 b
	July	6.6 a	7.3 a	7.1 a	3.6 b
	Aug.	3.1 a	3.5 a	8.6 a	4.9 b
	Avg	6.2 a	7.7 a	9.7 a	5.5 b

* Means in rows under the same variable followed by different letters are significantly different at the 5% level using L.S.D.
† 0 to 30 cm soil depth. Average of 32 measurements.

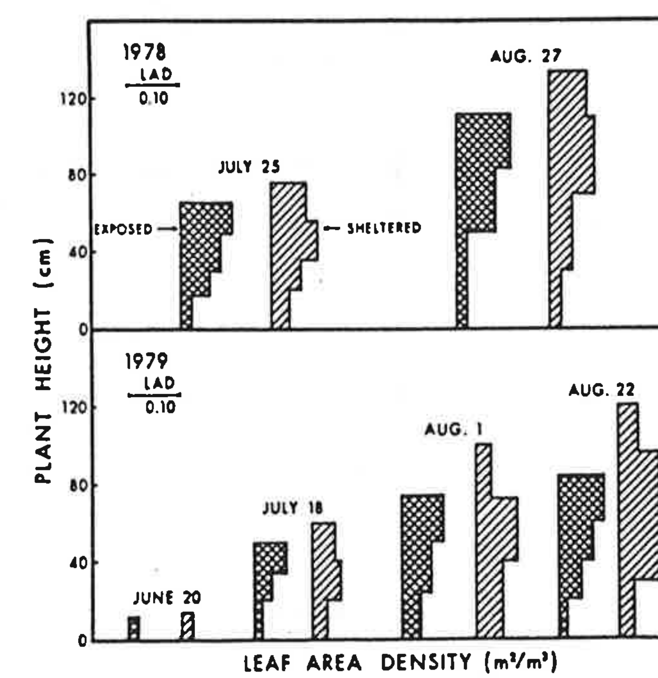

Fig. 3. Distribution of leaf area density (LAD) with canopy height in sheltered and exposed soybeans at various dates during 1978 and 1979 growing seasons.

within the canopy, deeper light penetration, and greater gaseous exchange (9). The vertical distribution of leaf density (Fig. 4) also indicated that sheltered soybeans had a more open canopy in the uppermost portions. These plants had a lower concentration of leaves in this part of the canopy. Leaf size distribution profiles (Fig. 4) indicated that larger and more mature leaves were closer to the top of the canopy in exposed than in sheltered soybeans. On these bases, restriction of light penetration by the uppermost canopy layers would be expected to be greater in the exposed plants. The influence of the canopy structures on light penetration and the canopy light climate was evaluated by measuring gradients of PAR in the canopies. The calculated K values were higher for the exposed soybeans, an indication of greater rate of PAR attenuation in the canopy (Figs. 5 and 6). The magnitudes of K obtained in this study were greater than that reported for 'Hawkeye' soybeans by Sakamoto and Shaw (18); but smaller than that reported for 'Amsoy' soybeans by Luxmoore et al. (10). The differences might be due to differences in canopy characteristics and other experimental conditions.

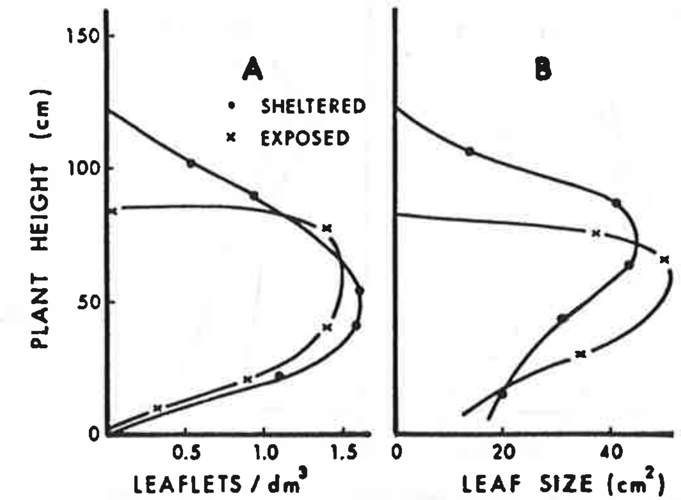

Fig. 4. Distribution of leaf density and leaf size with canopy height in sheltered and exposed soybeans on 22 Aug. 1979.

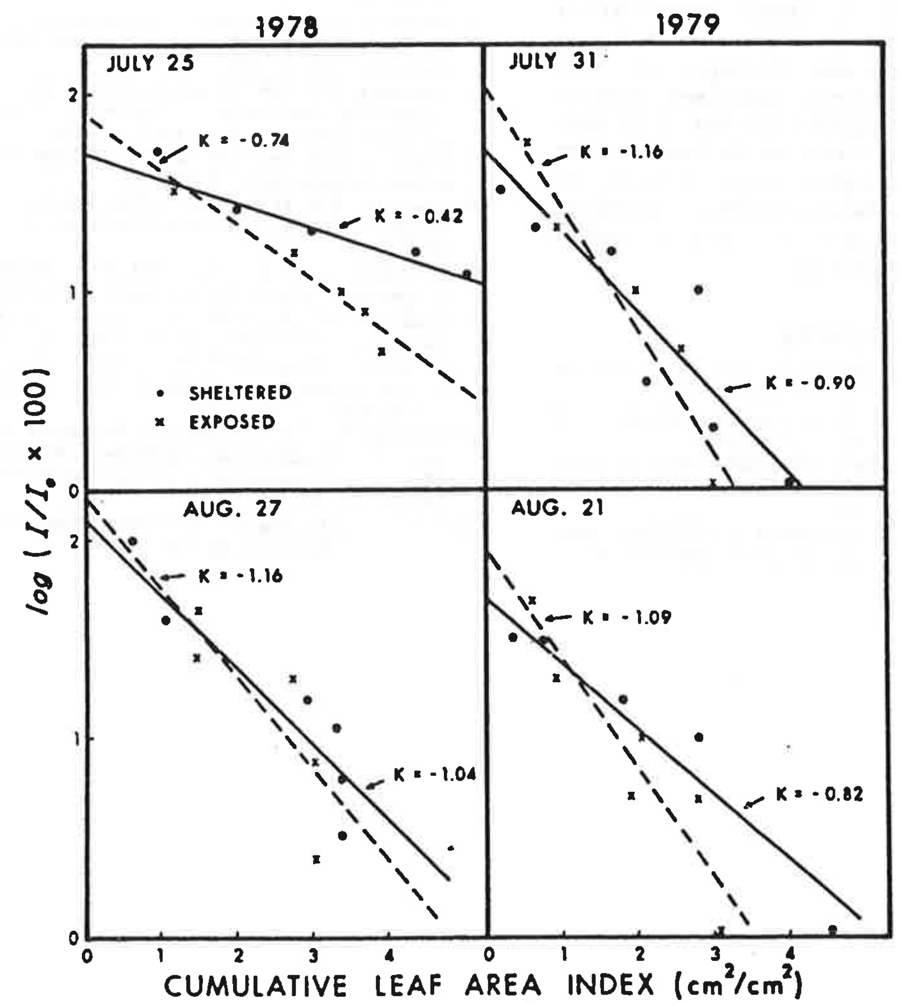

Fig. 5. The relationship between cumulative leaf area index and the logarithm of the relative light intensity at various depths in sheltered and exposed soybean plant canopies.

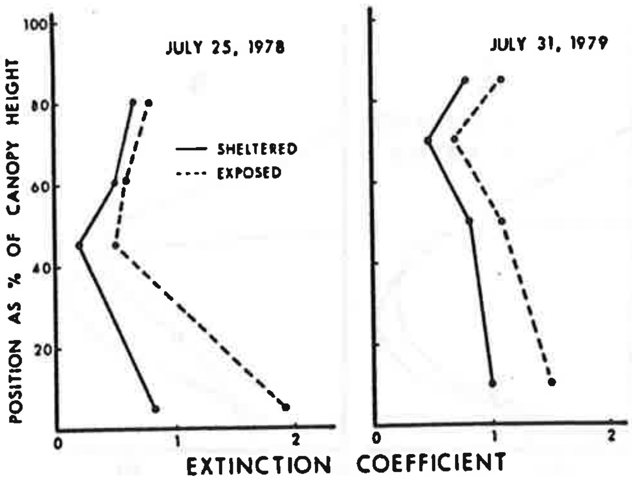

Fig. 6. Vertical profiles of light extinction coefficient in sheltered and exposed soybean plant canopies.

The results of this study agree well with earlier findings that light penetration into the soybean canopy is very much restricted by a dense leaf layer in the uppermost portions of the canopy (20, 21). Lower canopy LAD in sheltered soybeans resulted in deeper penetration of incident PAR to lower canopy strata. The improved canopy light climate, together with a better plant water status accounted for the increased growth and yield of the sheltered soybeans. Cultivar selection on the basis of these physiological and morphological responses to shelter should lead to increased soybean production. Models for predicting soybean performance need to accommodate any changes in canopy morphology.

REFERENCES

1. Bagley, W.T. 1964. Response of tomatoes and beans to windbreak shelter. J. Soil and Water Conserv. 19:71-73.
2. Blad, B.L., and D.G. Baker. 1972. Orientation and distribution of leaves within soybean canopies. Agron. J. 64:26-29.
3. Brown, K.W., and N.J. Rosenberg. 1971. Shelter-effects on microclimate, growth and water use by irrigated sugar beets in the Great Plains. Agric. Meteorol. 9:241-263.
4. Fehr, W.R., C.E. Caviness, D.T. Burwood, and J.S. Pennington. 1971. Stage of development descriptions for soybeans (*Glycine max* (L.) Merrill). Crop Sci. 11:929-931.
5. Felch, R.E. 1964. Growth and phenological responses of irrigated dry beans to changes in microclimate induced by a wind barrier. M.S. Thesis. Univ. of Nebraska-Lincoln.
6. Frank, A.B., D.G. Harris, and W.O. Willis. 1974. Windbreak influence on water relations, growth, and yield of soybeans. Crop Sci. 14:761-765.
7. ----, ----, and ----. 1977. Plant water relationships of spring wheat as influenced by shelter and soil water. Agron. J. 69:906-910.
8. Johnson, T.J., J.W. Pendleton, D.B. Peters, and D.R. Hicks. 1969. Influence of supplemental light on apparent photosynthesis, yield, and yield components of soybeans (*Glycine max* L.). Crop Sci. 9:577-581.
9. Loomis, R.S., W.A. Williams, and A.E. Hall. 1971. Agricultural productivity. Annu. Rev. Plant Physiol. 22:431-467.
10. Luxmoore, R.J., R.J. Millington, and H. Marcellos. 1971. Soybean canopy structure and some radiant energy relations. Agron. J. 63:111-114.
11. Marshall, J.K. 1974. Effects of shelter on the growth of turnips and sugar-beet. J. Appl. Ecol. 11:327-346.
12. Monsi, M. and T. Saeki. 1953. Über den Lichtfaktor in den Pflanzengesell-schaften und seine Bedeutung für die Stoff produktion. Jpn. J. Bot. 14:22-52.
13. Pearce, R.B., R.H. Brown, and R.E. Blaser. 1967. Photosynthesis in plant communities as influenced by leaf angle. Crop Sci. 7:321-324.
14. Radke, J.K. and W.C. Burrows. 1970. Soybean plant response to temporary field windbreaks. Agron. J. 62:424-429.
15. ----, ----, and R.T. Hagstrom. 1973. Plant-water measurements on soybeans sheltered by temporary corn windbreaks. Crop Sci. 13:543-548.
16. Rhodes, I. 1973. Relationship between canopy structure and productivity in herbage grasses and its implications for plant breeding. Herb. Abstr. 43:129-133.
17. Rosenberg, N.J. 1966. Microclimate, air mixing, and physiological regulation of transpiration as influenced by wind shelter in an irrigated bean field. Agric. Meteorol. 3:197-224.
18. Sakamoto, C.M., and R.H. Shaw. 1967. Light distribution in field soybean canopies. Agron. J. 59:7-9.
19. Scholander, P.F., H.T. Hammell, E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.
20. Shaw, R.H., and C.R. Weber. 1967. Effects of canopy arrangement on light interception and yield of soybeans. Agron. J. 59:501-505.
21. Sivakumar, M.V.K., H.M. Taylor, and R.H. Shaw. 1977. Top and root relations of field grown soybeans. Agron. J. 69:470-473.
22. Stevenson, K.R., and R.H. Shaw. 1971. Diurnal changes in leaf resistance to water vapor diffusion at different heights in a soybean canopy. Agron. J. 63:17-19.
23. Van Eimern, J., R. Karshon, L.A. Raxumova, and C.W. Robertson. 1964. Windbreaks and shelterbelts. Secretariat of the World Meteorology Organization. Tech. Note No. 59, WMO. No. 147, 70 TP. Geneva, Switzerland.
24. Zohar, Y. and J. Brandle. 1978. Shelter effects on growth and yield of corn. Isr. For. Assoc. 28:1-4.